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January 24, 1994

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Mr. Steve Sharkey
Federal Communications Commission
Office of Engineering and Technology
2025 M Street, N.W.
Washington, D.C. 20554

Re: Notice of Written Ex Parte Presentation
PR Docket 93-61

Dear Mr. Sharkey:

Transmitted herewith, on behalf of Pinpoint Communications, Inc. ("Pinpoint"), for consideration in the above-referenced docket, is a report entitled "Review and Discussion of the Pinpoint ARRAY™ Network and Its Performance" prepared by Hatfield Associates, Inc. The report examines the design of Pinpoint's ARRAY™ system and discusses the test results obtained from Pinpoint's experimental operations in Washington, D.C. As the report explains, the test results demonstrate that the ARRAY™ system operates reliably as designed and is well-equipped to accommodate time-sharing in the automatic vehicle monitoring ("AVM") band. The report also describes tests showing the electromagnetic capability of the ARRAY™ system with local-area reader-tag systems.

Pursuant to Section 1.1206(a)(1) of the FCC's Rules, two copies of the report and this transmittal letter are being filed with the Commission's Secretary.

Please contact me if there are any questions regarding this matter.

Respectfully submitted,

David E. Hilliard

David E. Hilliard
Counsel for Pinpoint
Communications, Inc.

EAY/ean
Enclosures

cc: w/ enclosures:

Mr. William Caton, Acting Secretary (2 copies)
Mr. Ralph Haller
Dr. Thomas Stanley
Mr. Ron Netro
Ms. Rosalind Allen
Mr. Martin Liebman
Mr. Frank Wright

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FEDERAL COMMUNICATIONS COMMISSION
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Review and Discussion of the Pinpoint ARRAY™ Network and Its Performance

Hatfield Associates, Inc.
4840 Riverbend Road
Suite 4
Boulder, Colorado 80301

January 20, 1994

Ex parte presentation
PR Docket No. 93-61

Table of Contents

Review and Discussion of the Pinpoint ARRAY™ Network and Its Performance

Executive Summary

The Pinpoint ARRAY™ network is a new and important step in improving the efficiency with which the nation's streets and highways are managed. The ARRAY system integrates automatic vehicle monitoring with digital messaging in one radio design, permitting these two functions to be carried out simultaneously using a single transmitted signal. The ARRAY network is planned to be implemented in major markets nationwide and will provide a wide range of services, including commercial and government fleet monitoring and dispatching, traffic control, roadside emergency assistance, in-vehicle traveler assistance, and in-vehicle warning systems, among many others. The Pinpoint system will support Intelligent Vehicle Highway System applications now being evaluated by the U.S. Department of Transportation. The system operates in the 902-928 MHz band under "interim" provisions for Automatic Vehicle Monitoring service established under Part 90 of the FCC's rules; proposed "permanent" rules are under consideration. Pinpoint has received commercial licenses to operate ARRAY networks in more than ten major markets and expects to provide service nationwide with connectivity among all local ARRAY networks for transparency of operation.

Pinpoint operated a five-base-station ARRAY network in the District of Columbia and Northern Virginia for several months in 1993. This system functioned as a testbed for the refinement of the system design. Pinpoint completed a series of tests on this network to verify system accuracy, adequacy of radio coverage, reliability of message transmission, and compatibility with other systems using common spectrum. The principal conclusions of the analysis of the system design and experimental system test results are as follows:

1. The ARRAY network, including the base stations, Network Control Center, and subscriber TransModems, work as designed: the system as a whole effectively computes vehicle locations, whether the vehicles are moving or stopped, and allows reliable message transmission to and from TransModems using the same frequency band as the ranging function. The base station and TransModem designs are impressively simple, so that commercial versions of the network components should be quite affordable and service costs low.

2. The time-division-multiplexed nature of the basic system over-the-air protocol and the high position-fixing capacity of the system inherently allow effective time sharing with other competing wide-area systems using the same spectrum. The system design is therefore basically "friendly" to cooperative sharing arrangements and can accommodate such without redesign.

3. The compatibility tests show that the Pinpoint network can also coexist with local-area AVM systems operating in the same band without causing or receiving unacceptable levels of interference. Even when Pinpoint equipment operated in the very near vicinity of transmitters and receivers of a local-area system operating at the same frequency, the interference levels to both systems were insignificant and easily accommodated by the systems' over-the-air protocols and data processing components.

Section 5 of this report summarizes in greater detail the test results.

The Pinpoint network architecture adapts itself to different market coverage requirements through its dynamic "cluster" configuration. By defining a "cluster" as a set of base stations that receive a particular TransModem's transmission at a given point in time, the system design inherently provides good coverage for both messaging and ranging without requiring complicated analyses of frequency re-use patterns and the control structure complexity that would result from the rigid definition of clusters. Similarly, by computing position estimates using the time-of-arrival information from the base stations that are best situated for accurate position determination, the system architecture fundamentally avoids many of the geometric accuracy difficulties that often plague other, more inflexible, system designs.

The Network Control Center's interfaces are clearly defined to allow customers of network services to connect their host applications processors with the ARRAY network and allow their applications to request and obtain information from their fleet members using a simple basic set of messages. The NCC's responsibilities for computing positions and determining received message integrity allow it to communicate with user applications at a high level, and features such as group polling improve the ability of the overall system to handle large numbers of users with disparate applications needs.

1.0 Introduction

The ever-increasing use of this nation's streets and highways makes the development of efficient ways to manage mobile resources imperative. The Pinpoint ARRAY™ network represents a new and important step in meeting this need. The ARRAY system integrates automatic vehicle monitoring (AVM)[1] with digital messaging in one radio design, permitting these two functions to be carried out simultaneously on a single transmitted signal. The ARRAY network is planned to be implemented in major markets nationwide and will provide a wide range of services, including commercial and government fleet monitoring and dispatching, traffic control, roadside emergency assistance, in-vehicle traveler assistance, and in-vehicle warning systems, among many others. Many of these services will support Intelligent Vehicle Highway System applications.

This report includes functional and structural descriptions of the ARRAY network against the background of the regulatory status of AVM services and predecessor radionavigation and radiolocation systems. The report provides a detailed description of tests performed on the ARRAY system, including location accuracy, messaging performance, and electromagnetic compatibility with other AVM operations.

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[1] The FCC proposes to rename this service Location and Monitoring Service, or LMS, and expand its scope to permit the location of all objects, both animate and inanimate. The term AVM is preferred in this document, although both terms may be used at times.

2.0 *Regulatory background*

The Federal Communications Commission has authorized the use of radio frequencies in the 902-928 MHz band for AVM systems that use "non-voice radio techniques to determine the location of vehicles" and transmit "messages relating to vehicles being located."[2] The Pinpoint system discussed in this document uses part of this allocation. The Commission defines several classes of user in this band with different priorities for spectrum access. These are as follows, in descending order of priority:

1. ISM equipment, such as medical diathermy machines; this equipment is not, by definition, used for communications but to perform work and typically uses the heating effects of electromagnetic radiation for its designed purpose.

2. Government radiolocation systems, such as naval fire-control radar.

3. Private land mobile radiolocation systems, including Pinpoint's and others' AVM systems, as well as automatic vehicle identification systems.

4. Amateur systems, such as repeater control and voice and data communications.

5. Unlicensed equipment operating under Part 15 of the FCC's rules, including some wireless local area networks, wireless PBX terminal equipment, and some cordless telephones.

In this list, any class of users must accept interference from higher classes and further must not interfere with users in higher classes. The Pinpoint system, for example, must not interfere with the operation of government systems such as naval fire-control radars and must suffer any interference received from such systems. AVM systems are currently licensed on a shared basis amongst themselves.[3]

Pinpoint has operated an experimental system in the Washington, D.C., area for several months under a Special Temporary Authorization (STA) and recently received an experimental license covering such operations; this system served as a testbed and as a vehicle for

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[2] 47 CFR §90.239. This section of the FCC's rules contains interim provisions for AVM systems, including preliminary technical requirements.

[3] A later section discusses joint compatibility testing between Pinpoint and Amtech Corporation, a developer of automatic vehicle identification systems that operate under the Part 90 AVM rules. These systems are applied, for example, to electronic tag-reading for automatic toll collection.

demonstrating system operation to various observers, including trade press representatives and government officials. Pinpoint has also received licenses for commercial system construction and operation in more than ten major markets, and applications for a number of other markets are pending.

3.0 Radionavigation systems

The general issue of vehicle location has been addressed by various radio techniques for many years. The basic problem has historically been the determination of a vehicle's position (usually ships and airplanes) to aid the vehicle operator in navigation; these radio techniques have thus become known as radionavigation techniques. The evolving interest in the automated management of commercial and governmental agency vehicle fleets in recent years has resulted in a corresponding interest in adapting existing radionavigation technologies to fleet management applications. This adaptation leads to inherent inefficiencies for the fundamental reason that a radionavigation system is designed to compute and display a vehicle's position in the vehicle itself to aid navigation, while a fleet management system requires the vehicle's position to be known at the fleet dispatch or management center and generally not by the vehicle's operator. This means that a messaging function must be designed to transmit positions to the center using spectrum in addition to that already used for the position-determining function. As a result, the equipment in each vehicle is more complicated than necessary, because the messaging function requires a separate radio in addition to the navigation receiver. Furthermore, the receivers in this application are needlessly expensive, because each contains complex position computation functions that could be performed at a central site for the entire fleet.

Many types and generations of radionavigation systems have been constructed by the U.S. government since the World War II era. These systems typically have been developed and operated by the Department of Defense, although in recent years the Department of Transportation has joined DOD in a joint management agreement for certain of these systems.[4] Many, if not most, of these systems apply to specific Government functions, typically military ones. There are, however, notable exceptions which have been either designed for or adopted by commercial users for their use. The two most commonly used systems are Loran C and the commercial service supported by GPS, the Global Positioning Satellite system.

Loran C is a so-called "hyperbolic" system in which a user-operated receiver measures the difference in arrival times of pulses of very-low-frequency (VLF) energy transmitted by pairs of terrestrial radio transmitters. The receiver contains tables of transmitter locations that it uses to compute an estimate of its position in units of latitude and longitude based on arrival time differences from pulses received from two pairs of transmitters. Initially intended as a maritime navigation system for use in coastal regions and inland locations, such as large river systems and the Great Lakes, Loran C has also found a following among general aviation users and many operators of land vehicle fleets. Loran C radio coverage extends across the lower 48 states and

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[4] The authoritative U.S. Government document detailing the functions and operation of federal radionavigation systems is the *Federal Radionavigation Plan*, published biennially by the John A. Volpe National Transportation Systems Center in Cambridge, Mass. The 1993 version is available through the National Technical Information Service, Springfield, Va., as document number PB93-165702.

southern Alaska. There was a mid-continent coverage gap that has recently been filled by coverage from a transmitter chain extending northward from southeastern Colorado. The additional coverage improves the reliability of communication for terrestrial users. Loran C allows receivers to estimate their positions within about one-sixth of a mile in unobstructed areas over water or in flat terrain. Accuracies decrease in the presence of large obstructions and reflective objects, such as buildings.

The Global Positioning Satellite System is primarily a military system and uses a constellation of 24 satellites at an altitude of 10,900 nautical miles. User receivers require information from four satellites to obtain a three-dimensional position fix; a receiver with a separate altitude input can obtain a two-dimensional fix using three satellites. The GPS satellites transmit ephemeris data that completely specify each satellite's orbit; this information, when combined with a precise time code that each satellite also transmits, is used by the user terminals to compute their positions. Using the commercial positioning code,[5] position accuracies are around fifty meters. Although there are techniques to improve the accuracy of a GPS position fix, a receiver must be able to "see" four satellites in a suitable geometric distribution in order to obtain useful accuracies. This can be a difficult problem in urban areas as well as other areas where there are many obstructions, such as mountains and trees. Even though the 24-satellite constellation provides 24-hour coverage of the entire earth's surface, the stated accuracies may not be obtainable at any arbitrary time at all locations.

Consistent with radionavigation purposes, a receiver at the user's location determines the user's position in both the Loran C and GPS systems. If the user requires the position information at a central location, a separate radio transmitter is necessary to communicate the data. Thus, a centralized system such as a dispatch center containing a display of fleet vehicle current locations determined by Loran C or GPS receivers in the vehicles must include a separate radio communication network to relay each vehicle's position to the center. This is a fundamental shortcoming of both Loran C and GPS as they are used in AVM applications: they must be used in conjunction with a separate and independent radio network to communicate position data to a central location and to allow other communication between a fleet or other applications management center and user vehicles. Note that this defect arises not from any basic flaw in the design of either the Loran C or the GPS systems, but from the fact that neither system was fundamentally developed for AVM purposes. Both systems were developed specifically to allow the local determination of position to facilitate navigation; neither was designed to support directly the centralized determination and reporting of the current positions of multiple vehicles.[6]

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[5] The GPS satellites transmit two codes -- a "P," or precise, code that is encrypted and used in military applications, and a "coarse/acquisition," or C/A, code used by both military and commercial receivers.

[6] There are other problems as well: Loran C operates at about 100 kHz and suffers from

(continued...)

A natural consequence of this fact is that AVM systems using either of these systems for determining vehicle positions will be needlessly expensive.

Even systems that are designed from the outset to serve AVM applications use different parts of the spectrum for messaging and ranging. Some of these systems, such as Teletrac, require "forward links" to establish a separate communications channel to a mobile whose location is being determined. The FCC proposes to allow 250 kHz of spectrum for this purpose in addition to the two 8 MHz subbands for wideband pulse ranging.[7] Unlike Pinpoint's system, these systems may also require a third, narrowband, link for mobile-to-base communications for full utility.

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[6](...continued)
man-made noise interference, limiting its effectiveness in urban and suburban areas. Both Loran C and GPS suffer from blockage from buildings and other structures in urban areas, further limiting their usefulness.

[7] Notice of Proposed Rule Making, PR Docket No. 93-61, "Amendment of Part 90 of the Commission's Rules to Adopt Regulations for Automatic Vehicle Monitoring Systems," released April 9, 1993, para. 19 and n. 39.

4.0 The Pinpoint system

The Pinpoint system is inherently designed to minimize AVM system cost by computing vehicle location centrally while simultaneously providing two-way digital messaging between centralized applications processors and vehicles. The system design allows the use of inexpensive mobile radio units, called TransModem™ mobile radios, which are simple transponding and digital message interface devices. Centralized processors compute individual vehicle positions using time-of-arrival measurements on signals, including digital messaging, transmitted by a mobile and received at multiple base stations.

4.1 System structure

Figure 1 shows the overall Pinpoint system structure. The network is known as the ARRAY Network and comprises several basic components: the Network Control Center, the base stations, the TransModems, mobile applications terminals, and host applications systems. These functions are described in the following subsections, and section 3.2 discusses the details of system operation.

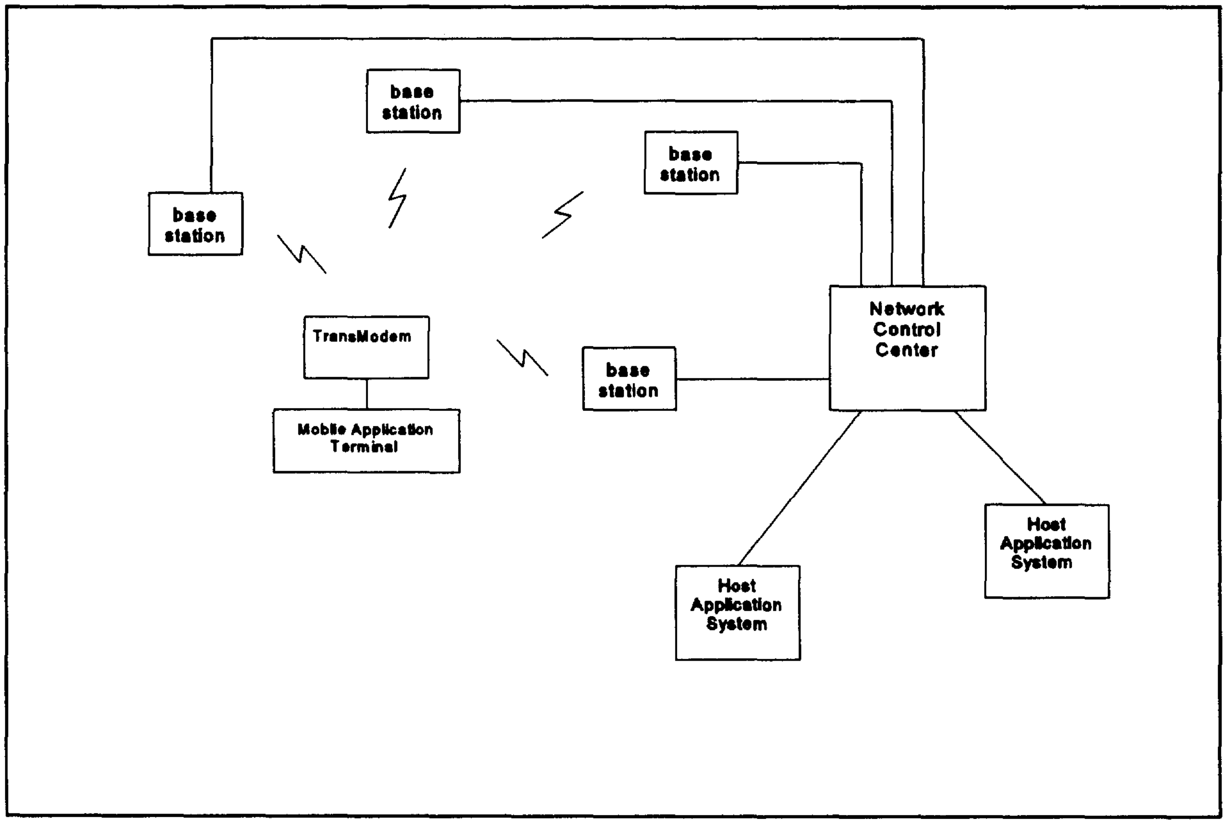

Figure 1 Pinpoint ARRAY network structure

4.1.1 Network Control Center

The Network Control Center (NCC) manages system operation and interfaces customer application systems to the network, performing protocol conversions as required. It contains a set of parallel processors that jointly perform all control functions; the processor array is fault tolerant. The NCC controls and schedules all transmissions from the base stations to the TransModems. It estimates the position of each TransModem according to the time difference of arrival of the TransModem signals received at the base stations using hyperbolic multilateration techniques.[8] It manages the base stations and insures that their internal time references are synchronized. The NCC can manage communications interfaces with NCCs in other areas to form a nationwide network.

4.1.2 Base stations

The ARRAY base stations incorporate fixed radio transmitters and receivers, along with ancillary equipment, including a vertically-polarized antenna. Base stations transmit data to TransModems under the control of the NCC and receive transmissions from the TransModems; each base station accurately times the received messages and forwards the time-stamped receptions to the NCC for processing and determination of location.

The implementation of the ARRAY network in any given market involves the placement of base stations to ensure adequate base station "geometries" for accurate vehicle location throughout the intended coverage area. Ideally, every time a vehicle is located by the ARRAY system, it will be within a polygon defined by four or more base stations -- known as a "cluster" -- that are involved in determining the vehicle's position. A particular "cluster" is defined only for the duration of a particular position fix for a particular vehicle and is not a static attribute of the system architecture. As the vehicle moves, the composition of the "cluster" that is used to determine its location will change accordingly. Over any given period, a single base station could, and is likely to, be part of multiple, different "clusters" for different mobiles. In short, while in one sense a given market implementation could be said to consist of one or more "clusters," the cluster concept is dynamic.

4.2 System operation

The Pinpoint system was developed specifically to integrate vehicle position determination with digital messaging between vehicles and central sites, and the degree of integration is so complete as to use a common signal for both messaging and ranging. The system computes vehicle positions centrally, which is appropriate for most fleet applications. It generally isn't necessary for drivers to know their current location, but fleet management systems, including dispatch centers, often need to know the whereabouts of the individual fleet members.

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[8] "Hyperbolic multilateration" is described in a later section.

The Pinpoint system is entirely centralized, and the NCC controls all communications to and from the TransModems (except for TransModem service requests) in the users' vehicles. The NCC determines a TransModem's position by performing time-of-arrival difference measurements on messages responding to polls or from service requests initiated by the TransModems. The NCC initiates the polled position-determining function by scheduling transmissions to vehicles whose positions are desired. A designated, or "master," base station transmits a signal to a given TransModem, which transmits an acknowledging response message. Generally, each of the local base stations in the cluster will receive and "time-stamp" the transponded signal from the TransModem and then forward the received messages and their arrival times to the NCC. The NCC then computes the differences in arrival times for each pair of base stations and estimates the TransModem's position; the position information may in turn be transferred to an applications processor, possibly for display on an electronic map board or terminal screen. The message sent to the TransModem will often contain data for use by other equipment in the vehicle, and the response message may contain information from the vehicle that will be sent to a customer applications processor after initial link-level processing by the NCC.

More than one base station may transmit. The NCC control software is "adaptive" in that it retains a record of the recent history of TransModem activity and location, including information regarding which base station the mobile may have responded to in recent system cycles. If a mobile becomes hidden from the base station which it has been receiving, the NCC will instruct other base stations to poll the mobile. If the mobile responds to a base station other than the master, the NCC software notes which base station is in contact and will in subsequent cycles rely on that base station for communication with the mobile in question. Accordingly, as with "clusters," the designation of a "master" base station for a mobile is dynamic and responsive to changing circumstances.

In this dynamic radio landscape, some clusters may exhibit enough physical separation to provide sufficient cochannel interference margin for reliable reception so as to permit simultaneous operation, thereby increasing the capacity of the ARRAY implementation. At times, therefore, an ARRAY system implementation will support a dynamic frequency reuse pattern analogous to those employed by cellular mobile telephone systems.[9]

The system operates with five basic message types:

1. A base-station-originated poll to stimulate a position-determining response from a transponder and to set up a transaction with the transponder;

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[9] An important difference is that the ARRAY network operates on one wideband channel, making reuse an opportunistic event rather than a part of the "permanent" system design, whereas cellular systems use many channels, permitting a static frequency reuse pattern incorporated into the cellular system architecture itself.

2. The corresponding poll response from the transponder inbound;

3. An autonomously-generated service request from a transponder;

4. A message, including a variable number of contiguous timeslots, outbound from the network to a transponder;

5. A message containing a variable number of packets picked up from a transponder.

All messages received from a transponder (message types 2, 3, and 5) result in a position computation.

The following sections describe the system operation in greater detail.

4.2.1 Messaging and ranging protocol

Communications from the base station are organized into a repetitive "system cycle," which is a frame of information divided into three segments of variable length depending on current system requirements. The first segment contains "housekeeping" information, including a system synchronization signal, system time-of-day, system call sign and other identification parameters, and pointers to boundaries of other fields in the current cycle. Base stations also perform self-calibration and other special functions during this interval. The second segment is used by TransModems to request service from the network. The system transmits polls in the third segment to determine individual and multiple vehicle positions, transmit messages to specific vehicles, set up groups, and collect messages scheduled for specific time slots. Figure 2 shows the overall system cycle.

For purposes of discussion, this discussion assumes that the Pinpoint system is the only multilateration operator in the band. It is important to note, however, that the ARRAY system can readily accommodate time sharing of the spectrum by competing systems: because the Pinpoint system operates in a time-division-multiplexed fashion entirely within one band, the basic design fundamentally lends itself to time sharing. Furthermore, cooperative synchronization required for sharing is easily implemented by the ARRAY network, because there is a single "master timing base station" that broadcasts timing references to the entire network. A single synchronization signal transmitted to the NCC so that it can send suitable instructions to the master timing base station is essentially all the coordination that is required for sharing.

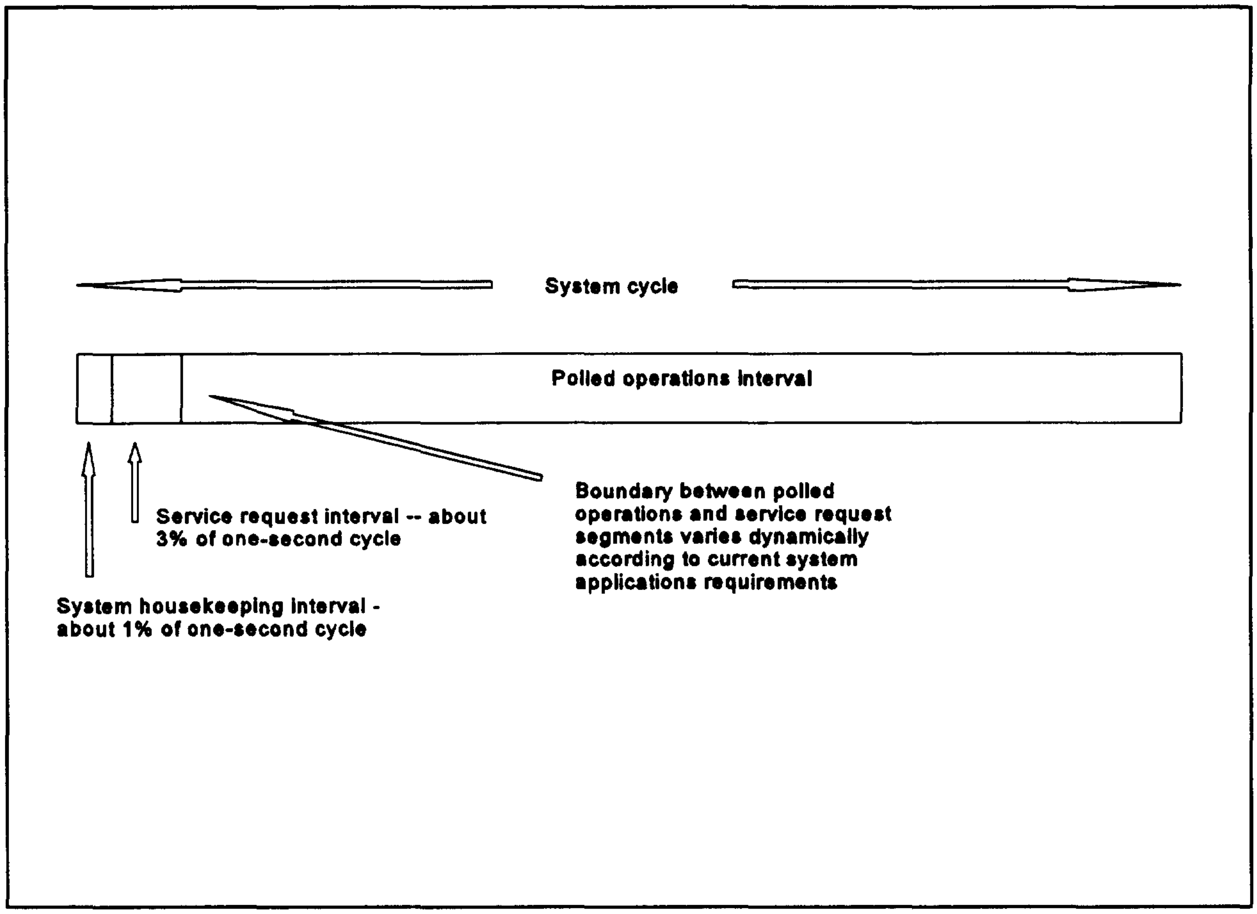

Figure 2 System cycle

An overall system cycle of one second duration contains about 1500 time slots; each cycle and each slot within a cycle are uniquely identifiable. When the network master timing base station begins a system cycle, it broadcasts the system time during the housekeeping interval, and TransModems synchronize themselves with the cycle by counting time slots. The housekeeping segment is quite short and normally will occupy only about 1% of the complete system cycle. Selected other base stations retransmit the timing signals to improve synchronization coverage. The system transmits a poll and receives a poll response in a single time slot; the time slot duration thus is long enough to accommodate the polling message, the TransModem response message, and the longest expected round-trip propagation delay in the system.[10] The duration, in time slots, of the polling and service request intervals in the system cycle also varies according to the current mix of active system applications; typically, however, the service request interval

[10] In a typical system, the longest two-way delay corresponds to the base station spacing, so the duration of a slot depends on the specific local system implementation.

occupies about 3% of the system cycle. The master timing base station broadcasts the identity of the last available service request time slot in the current system cycle during the housekeeping segment; the end of this time slot is the boundary between the service request and polling segments. The NCC computes this boundary during each system cycle according to the amount of currently-queued outbound[11] message traffic and the number of inbound service requests; it increases and decreases the duration of the request segment in response to the measured service request collision rate.

4.2.1.1 Housekeeping cycle details

The master timing base station transmits a time synchronization message at the beginning of the housekeeping interval, and other designated base stations retransmit this message during the next time slot. These "secondary repeating base stations" serve to improve the system synchronization coverage. The system transmits the time slot number of the boundary between the service request and polling segments of the system cycle, and TransModems synchronize themselves with the system cycle by counting time slots. Thus, each time slot does not contain an explicit address but is located by the system components by a simple counting process beginning at a known reference time in the housekeeping interval.

4.2.1.2 Polling cycle details

Transponders are capable of responding to several possible addresses. The principal address is the same as the TransModem's serial number,[12] and each device may also be assigned several secondary, or "alias," addresses. Furthermore, a common secondary address may be assigned to several transponders to allow the system to define groups and subgroups to facilitate outbound communication with several vehicles simultaneously. In a fleet application, for example, a single poll could obtain the current locations of all vehicles in the fleet. When a group is addressed, the transponders in that group respond to the poll in a preassigned sequence, thereby avoiding collisions among transmissions of the group members. The ability to poll all members of a group improves system capacity, because a single polling message stimulates responses from all group members. In a group of, say, one hundred members, two hundred messages -- 100 polls and 100 poll responses -- would be transmitted if group polling were not available; with group polling, only 101 messages are transmitted -- one poll and one hundred responses. A secondary address may also be unique to a transponder to allow it to respond in a specific way, depending on the application being served. As an example, a display register containing stock quotes could have a secondary address in a number of given transponders, so that messages sent to that address

[11] In this report, the "outbound" direction is toward the mobile units from the base stations, and the "inbound" direction is from the mobiles toward the base stations.

[12] The serial number is a 32-bit word; this allows nearly 4.3 billion unique primary addresses.

would result in the information display in several vehicles simultaneously. As is the case with all TransModem transmissions, the system also computes the transponder's position from grouped polling responses.

The polling process allows the system to determine the location and status of any transponder at any given time. It does not, however, provide a suitable mechanism to retrieve messages originated by remote transponders, because every transponder in the system would need to be polled periodically. This periodic polling would heavily constrain overall system capacity. To improve the efficiency of inbound message transfer, the system cycle includes a request segment, during which only those transponders with messages to send autonomously transmit service requests to the NCC to schedule "pickup" service to transfer the messages to the network.

4.2.1.3 Request cycle details

When a transponder requires service from the network, it notes the service request segment's boundary timeslot number transmitted during the housekeeping cycle and randomly selects a timeslot from that segment to transmit its request. It then waits to receive service or an acknowledgement from the system.[13] If the system does not respond within an interval that depends on a system activity level indicator also broadcast as part of the housekeeping information, the transponder waits a random interval and then selects another request timeslot, again at random, and retransmits its request. If the retransmission fails, the transponder increases its retransmission delay and repeats the process. This is fundamentally a slotted Aloha contention scheme, with congestion stability controlled by the increasing retransmission delay.

Certain applications, such as public safety or ambulance dispatch, may require very fast response in emergency conditions, notwithstanding currently heavy network activity. This facility is handled on two levels: first, the subscriber profile includes high-priority handling of service requests, and the service request itself contains a "high priority" operation code. Second, at the option of the subscribers requiring fast service request processing, the service request segment is further divided into "normal" and "high priority" subsegments, with the information about the segment sizes broadcast during the housekeeping segment. Processing of services requests is handled as described above, except that only those subscribers qualified as "high priority" users may use the reserved high-priority service request segment when they have messages requiring nearly immediate transmission.

The request packets do not contain the information to be sent by the transponder; they function as scheduling requests, and the system schedules a polling message and a suitable number of contiguous timeslots in a later system cycle to retrieve the information from the requesting transponder.

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[13] The NCC controls the timeout interval according to the current system loading.

4.3 *Message encoding and transmission*

The Pinpoint system uses spread spectrum pulse expansion and compression techniques, similar to those used in some modern radar systems, for transmitting its radio frequency ranging and message signals. The heart of the technique is embodied in a surface acoustic wave (SAW) device serving both as a sequence generator and a correlator for signal reception and detection. The transmitter uses a modified form of MSK (minimum-shift keying) modulation.

A combination of encoding techniques is used to encode data into the expansion sequences, so that both message data and ranging timing are carried in the same signal. In the test system, each ranging pulse contains two bits. In the production system, between four and eight bits will be encoded into each ranging pulse.

4.4 *Location determination*

As noted in an earlier section, the Pinpoint system determines transponder location using a "hyperbolic multilateration" technique. This term derives from the fact that the locus of all points having a constant difference in distances from two fixed points is a branch of a hyperbola, with the baseline joining the two fixed points forming the axis of symmetry. This is the basis for several different radiolocation systems, including Loran C, as described above in Section 3.0, as well as the Pinpoint system.

The Pinpoint system operates in a "reverse" fashion in comparison with the Loran C system in that a single mobile unit, and not the base stations, transmits the ranging pulses, and from multiple base stations' measurements of signal arrival time, an NCC can compute the various arrival time differences used in the same location calculations. Although sufficient signal strength from multiple base stations may be available outside a "cluster" boundary to allow time difference determinations at the base locations, hyperbola pairs may intersect at small angles, a condition which can lead to increased error in position estimation. The Pinpoint system in general uses several baseline pairs to refine the accuracy of the position estimate; the system develops the most accurate results when vehicles to be located lie within a "cluster" boundary. Pinpoint intends to ensure this result in the vast majority of cases through appropriate placement of base stations.

4.5 *User applications*

The Pinpoint system performs basic position computations and sends and receives information to and from TransModems according to user requirements. User systems generally interface with the Pinpoint system at a subscriber port of the NCC level and at the serial data port of the TransModem. The following sections describe the interactions between the Pinpoint network and the user devices.

4.5.1 *Host applications*

User applications reside in user-provided host applications processors, connected to the Pinpoint system through standard communications interfaces using dedicated landline or other facilities of suitable bandwidth. The NCC uses TCP/IP (Transmission Control Protocol/Internet Protocol) as its fundamental ("native") transport protocol; host applications can also use error-correcting modems on asynchronous connections without using TCP/IP.

Pinpoint has defined a message-oriented protocol for use between host applications and the NCC; the basic messages in the set, along with their direction of transmission, are as follows:

Get Current Vehicle Location	application → NCC
Get Vehicle Group Locations	application → NCC
Get Current Vehicle Velocity	application → NCC
Get Last Known Vehicle Location	application → NCC
Send Data to TransModem/Group	application → NCC
Receive Data from TransModem	NCC → application
Confirm Data Delivered to TransModem	NCC → application
Login to Network	application → NCC
Logout from Network	application → NCC

Host processors and the NCC use these basic messages to communicate information required by the user application. A later subsection describes typical applications.

4.5.2 *TransModem applications interfaces*

The TransModem can interface user equipment located in a vehicle with the ARRAY network. The physical interface is a nine-pin connector using RS-232C signal definitions. Applications located in the vehicle are called "mobile applications" in this discussion; host applications are those residing in user host processors, as described in the previous subsection. The TransModem supports four interface modes:

Binary data mode This is the default mode and is used for general data communications, including unformatted messaging and file transfers to user applications residing in host processors by mobile equipment through the TransModem. In this mode, a mobile application may communicate with only one host application.

Smart data mode This is a Pinpoint-defined proprietary protocol that allows, among other things, the ability for a mobile applications system to communicate with several different host applications.

TTY data mode This mode supports devices using terminal emulator software in TTY mode and provides limited character editing and local echo (the latter is optional).

Command mode This mode allows the TransModem to communicate directly with the mobile application using Hayes-compatible AT commands (EIA/TIA-602); this makes the TransModem compatible with commercially-available PC communications software that typically uses the AT command set and can be employed to facilitate communication within a user's system.

4.5.3 Typical applications

The basic application supported by the Pinpoint system is vehicle location with integrated messaging. The NCC includes vehicle location information in every message transmitted to a host application that involves one of the user's TransModems. The NCC-to-host message header contains the time of day (expressed to tenths of seconds) along with the TransModem's longitude and latitude, each expressed in hundredths of seconds. When a host application sends a message to the NCC requesting activity with a particular TransModem or group of TransModems (using, *e.g.*, the *Send Data to TransModem/Group* message), the NCC hunts for the TransModem or for the entire group, as required. If the TransModem is outside the ARRAY network coverage area, the NCC accordingly notifies the host application. The TransModem will autonomously register itself when it enters an ARRAY network coverage area.

The Pinpoint network is designed for short data messages exchanged between the NCC and TransModems. The system allows priority scheduling of messages at five levels which (excluding the public safety level) are distinguished by service price. They are, in descending order of priority, as follows:

Public safety Virtually immediate access available only to public safety agencies; such agencies would have access to other priority levels for non-emergency communications;

Emergency Provides virtually immediate access to non-public-safety users;

Standard Normal access priority;

Deferred	Lower-priced service for messages that can tolerate buffer delays;
Off-peak	Lowest-priced service in which messages are transmitted during off-peak times.

A public transportation system is a useful example of an ARRAY network application. Managers of fixed-route transit systems face many challenges in managing their fleets. These challenges involve the need to know the location of fleet vehicles as well as the requirement for reliable communications between a central dispatch facility and the vehicle drivers.

Transit systems generally need to reduce vehicle and driver layover times, because they do not produce revenue when they are not hauling passengers. A related problem is "platooning," the tendency of vehicles to "bunch up" along a route. With accurate knowledge of vehicle positions and a reliable communications mechanism to allow dispatchers to instruct drivers to change their average speed to even out the vehicle flow, transit managers could improve customer service and simultaneously increase efficiency.

A combined vehicle locating and communications system, such as Pinpoint's ARRAY system, can provide the information needed by computer-aided vehicle management systems to assist dispatchers in determining necessary speed adjustments and communicating orders to drivers, rerouting buses, changing stops, and changing the number of vehicles on routes. A graphical computer display showing a city-wide map can show the status of the entire fleet. Such a display can also show alarms indicating, for example, whether a vehicle has strayed from its fixed route, has departed from its schedule, or is disabled. The Pinpoint system can also improve driver and passenger security by providing a means for nearly instantaneous transmissions of emergency signals for prominent display on the dispatch screen.

Support vehicles can also be tracked, perhaps using different display icons. The tracking display might, for example, show the positions of supervisors' cars and maintenance vehicles so that the closest supervisor or maintenance technician may be dispatched to assist a bus with maintenance or other problems. Centralized computer-aided monitoring of fleet operations also can reduce the need for supervisors to travel to selected stops to monitor on-time performance, tending to reduce operating expenses.

The flexible addressing capability of the system can allow dispatchers to display individual vehicle positions, locations of all buses on a specific route, supervisor vehicle positions, and many other combinations of vehicle positions, possibly in conjunction with expanded map displays for increased detail. Furthermore, this application would be one of many independent applications served by an area-wide ARRAY network. The system would be simultaneously serving public safety agencies and commercial users with widely disparate applications needs.

5.0 Pinpoint ARRAY network testing

Pinpoint operated an experimental ARRAY network in Washington, D.C., during the summer and fall of 1993 for system testing and demonstrations. Initial testing began in July, and, starting in October, Pinpoint conducted performance tests on this network. This section describes the tests and discusses their results.

5.1 Test design

The Washington-area ARRAY experimental network comprises five base stations, with two in the District of Columbia and three in Arlington, Va. The base stations lie in a roughly circular pattern about three miles in diameter which encompasses the western half of The Mall, the Roosevelt, Memorial, and "Fourteenth Street" bridges, the Pentagon, and Fort Myer. The interior of the circle, as noted earlier, is the area in which the system most effectively and accurately determines a vehicle's location. Figure 3 shows the base station locations and the route travelled by the van containing the mobile test equipment, as described later in this section.

The area selected for the tests includes a variety of test conditions: line-of-sight paths, urban "canyons," a wide range of background electromagnetic radiation, heavy land vehicle traffic, and heavy low-altitude aircraft traffic. Because District of Columbia ordinances restrict building heights, average building heights tend to be more uniform than they are in other cities. As a result, it is difficult to place base stations in the downtown area that are much higher than surrounding buildings to achieve line-of-sight propagation to locations along city streets. In this respect, the urban propagation conditions are something approaching "worst-case" in the tests. Airplanes, particularly airliners, are efficient scatterers of radio-frequency energy, especially at the frequencies used by the Pinpoint system. The test vehicle route passes very close to National Airport, and the proximity of airplanes to the ARRAY network elements significantly worsens the multipath environment, making the tests even more stringent.

The investigation consisted of three classes of tests. Pinpoint equipped a van with a TransModem and suitable test equipment for the tests. Figure 4 shows the test equipment connections. The items tested and the corresponding test procedures are as follows:

> *1.* *Location "dispersion,"* which is the scattering of position calculations made for a TransModem at a fixed location based on time-of-arrival difference measurements using different pairs of base stations in a single ranging operation. The test van stopped at numerous test points along the route to allow the system to complete 25 location computations using the ARRAY network in a five-base-station configuration.
>
> 2. *Data "reliability,"* a measure of error rate in messages between TransModems and base stations. This test consisted of two parts -- signals measured at the TransModem location, and signals measured at base station

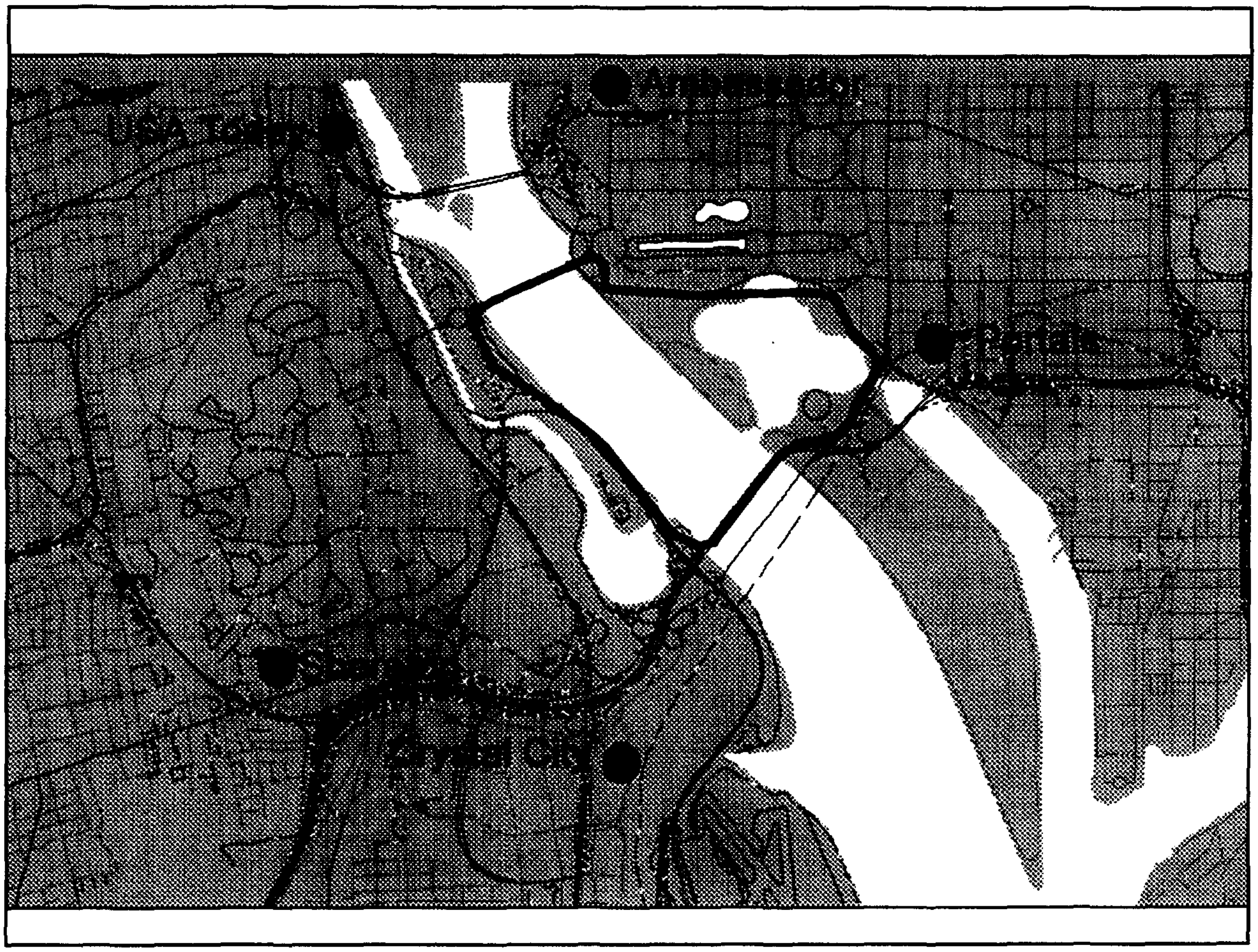

Figure 3 Base station locations and test vehicle route